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Agathis robusta (C. Moore ex F. Muell) F.M. Bailey Queensland kauri

Araucariaceae Aracaria family

U.S. Forest Service
Pacific Southwest Library and Information Center
1323 Club Drive
Vallejo, CA 94592-1110

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HABITAT

Native Range

Agathis robusta, commonly known as Queensland kauri, is a handsome tree when young, and in old-growth stands it is majestic (fig. 1). Although the range of Queensland kauri is extensive, it occupies a limited area (fig. 2). The species is found in stands on Fraser Island near the coast of southern Queensland, Australia, in several stands on the mainland nearby, and in a few stands in northern Queensland between 15 and 19 °S latitude (*1*). A subspecies of Queensland kauri, *A. robusta nesophila,* is found in a few locations in southeastern Papua New Guinea and the island of New Britain (*2, 26*). Although the two populations and the subspecies differ slightly, enough unity probably exists to ecologogically describe and manage them similarly. The accessible stands of mature Queensland kauri have been heavily reduced by repeated selective logging; only scattered relicts remain with fairly abundant but often overtopped reproduction (*26*). About 760 ha have been planted in Queensland (*2*). Successful trials of the species have been conducted in India (*13*), South Africa (*3*), Uganda (*6*), Mauritius (*22*), and Puerto Rico.

Queensland kauri is also grown as an ornamental in many tropical moist areas of the world. With better management, the species should gradually improve its position in native stands and eventually gain acceptance as a timber tree in appropriate locations around the world.

Climate

Queensland kauri is restricted to humid regions with well-distributed rainfall. Mean annual precipitation ranges from 1100 to 5000 mm and is more concentrated during the summer months (*1, 26*). However, rainfall in the driest month is still 25 to 35 mm (*1*). Queensland kauri grows from near sea level to a 900-m elevation. Temperatures are described as warm in summer (30 to 32 °C maximum) and mild in winter (13 to 19 °C minimum in the north and 6 to 8 °C minimum in the south). At elevations above 600 m in the southern part of the range, there may be 20 to 30 frosts per year (*22*).

Soils and Topography

Queensland kauri is not exacting in its site requirements. It grows on all types of soils, from deep sands to stony clays, but it does best on deep, well-drained granite-derived soils (*1*). No reference of tolerance to poorly drained soils was found in the literature; however, the species is normally found on well-drained ridges, slopes, and valleys. In Uganda, Queensland kauri has done well on volcanic clays and coral-derived soils (*6*). In Puerto Rico, the species tolerates pH's ranging from 4.2 to 8.1. Leaf leachate of *A. australis* has been shown to mobilize iron, a step in the soil podzolization process, and this is probably true for all *Agathis* species (*24*). Podzolization is likely in base-poor soils, but not in base-rich soils. The

Figure 1.—Agathis robusta *growing in Puerto Rico.*

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species does not grow naturally on lateritic podzolic soils on the coastal lowlands of Queensland and grows very slowly when planted there. It grows at normal rates with supplemental nitrogen, however (*20*).

Associated Forest Cover

In the southern portion of the range, Queensland kauri grows as a rain forest dominant with the more important associates *Gmelina leichardtii, Beilschmiedia obtusifolia, B. elliptica, Litsea leefeana,* and *L. reticulata* (*13*). Another source lists: *Flindersia schottiana, F. bennettiana, Pseudoweinmannia lachnocarpa, Brachychiton acerifolium, Backhousia myrtifolia,* and *Rhodamnia trinervia* (*1*). In northern Queensland, the species dominates a climax community that includes *Flindersia mazlini, F. acuminata, F. ifflaiana, F. pubescens, F. brayleyana, Xanthostemon pubescens,* and *Cardwellia sublimis* (*9*). On alluvial soils and deep moist loams, Queensland kauri is still a dominant but is represented by only 2 to 7 trees/ha and is associated with *Cardwellia sublimis, Embothrium wickhamii, Endiandra palmerstonii, Castanospermum australe, Flindersia brayleyana, Cryptocarya bancrofti, Eugenia gustaviodes,* and *Blepharocarya involucrigera.* No associates are mentioned for the Papua New Guinea subspecies.

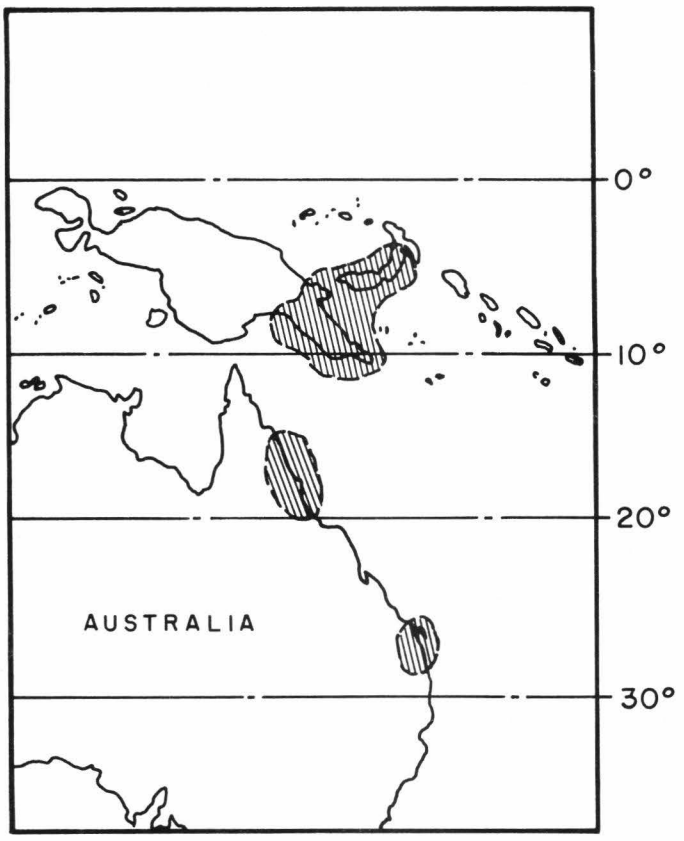

Figure 2.—*Areas within which natural stands of* Agathis robusta *are found in Australia and Papua New Guinea .*

LIFE HISTORY

Reproduction and Early Growth

Flowering and Fruiting.—Queensland kauri is monoecious, but dichogamy (asynchrony of male and female flowering on the same tree) probably prevents self-pollination (*26*). The male strobili are 4 to 8 cm long and borne on leaf axils near the ends of the branches (*13*). Pollen requires 80 percent relative humidity and temperatures not lower than 25 °C to germinate (*26*). The female cones are ovoid, 10 to 13 cm long, and 10 cm in diameter (*8*). Cone scales are about 2.5 cm across, closely overlapped, and thickened at the base with a groove in which the seed develops. The seeds are 1.25 cm long with an asymetric wing 2.5 cm long. The cones emerge from June through July and, after fertilization in September, require 16 months to produce mature seed (*26*). Cones are first produced when trees are about 20 years old.

Seed Production and Dissemination.—The cones mature in January and begin disintergrating while still on the tree (*18*). As the seed is released, it spirals downward in the wind. In Australia, seeds are eaten by cockatoos, whose activity indicates that the seed is ripe (*26*). Rodents also attack cones and seeds (*9*). In the native range, the moth *Agathiphaga queenslandensis* infests many cones; its caterpillers develop within the cones and destroy most of the seed (*8, 26*). In one sample in South Queensland, 340 to 435 seeds/cone were counted, but only 10 percent were sound (*18*). The same investigator reported 96-percent germination of filled seed. There are about 21,400 seeds/kg at 5-percent moisture content (*26*). Seed viability is very short, not more than a few weeks (*26*). Viability can be extended by drying the seed and storing at 3 °C (*2*). Seed availability and storage is a major obstacle to extensive plantation culture of this species.

Seedling Development.—Experience from a related species, *Agathis dammara,* indicates that germination is epigeal and occurs between 7 and 14 days after planting (*26*). Soaking in water for 24 hours before sowing is beneficial. Seed beds in the nursery need to be shaded to prevent scorching of the seedling leaves. In Queensland, nursery beds are sprayed to prevent attack by fungus and thrips. Seedlings are potted when they are 7 to 10 cm tall and outplanted after they reach a 0.25- to 0.5-m height (when they are about 1 to 1.5 years old). Alternately, for developing bare root stock, seedlings are root-wrenched at 3 and 6 months old. Investigators in Queensland compared seedlings bare rooted, bare rooted after wrenching, in tubes, and in bamboo pots and tested the best planting ages for seedlings (*18*). Seedlings in tubes had 100-percent survival, and wrenched seedlings were superior to bare root seedlings without wrenching. Best growth and survival was obtained by planting-out seedlings at 2 years old. The wet autumn was generally chosen for planting, but planting was successful throughout the year with tubed stock. Large seedlings better withstand heavy natural competition and resist periods of hot, dry weather. They should be 30 to 40 cm high with a 30-cm taproot cut back to 18 cm and allowed to stabilize in the planting tube for 2 months before out-planting (*9*).

In Java (26), a low-cost method for obtaining seedlings

involves cultivating the ground below mother trees. A dense stand of seedlings (wildings) develops under the mother trees; these are then dug up and planted directly in the field. In Puerto Rico, essentially the same procedure is followed except that the wildings are dug up when they are about 10 cm tall, transferred to plastic planting bags, and grown to 0.25 to 0.5 m before planting in the field. Ninety-seven-percent survival was obtained in one small plantation using this method.

Natural reproduction often occurs in abundance in the shade under or near mother trees. Although the seedlings may survive for many years in the understory, the forest canopy must be opened to allow light to enter for them to grow into the overstory (*9, 28*).

Vegetative Reproduction.—Queensland kauri is probably the easiest *Agathis* to root (*26*). Cuttings made from seedlings of *Agathis* species grow rapidly, but if made from lateral branches the new trees will assume a plagiotrophic growth habit (*29*). Stem cuttings have been reasonably successful. A novel vegetative propagation technique involving root suckers has produced good results. Seedlings are raised in plastic tubes 50 mm in diameter. The tube is slipped part way off, and the cylinder of soil containing the root is cut transversely leaving the top with a shortened root system and a severed tap root that will then sprout and grow. The resulting suckers grow straight, and the procedure can be repeated with the same top several times (*12*). To overcome plagiotrophic problems associated with cleft grafting, a method involving the grafting to seedlings of a bark patch removed from near the apex of a leading shoot has been developed (*17*). Dormant buds on the bark patches develop into new leaders. If not too old, Queensland kauri will coppice if cut or burned (*3, 18*).

Sapling and Pole Stage to Maturity

Growth and Yield.—Height growth of Queensland kauri is not rapid. In a number of tests, average height growth varied from less than 0.5 m/yr to 1.5 m/yr (*26*). Height growth, however, is sustained and steady for 20 to 30 years (fig. 3). Diameter growth in plantations can be impressive. A South African plantation gained 2 cm/yr when 15 years old, but was growing just 1 cm/year when 40 years old (*3*). An average of 12 trials in various parts of the world ranging from 9 to 25 years old averaged 12 mm in mean annual diameter increment (*26*). Individual diameter increment in some of these plantations was probably limited by crowding. In several small plantations in Puerto Rico, trees have grown a little less than 1 m/yr to an apparent near-maximum height of 20 to 26 m and have added 1 to 2 cm in diameter per year. A roadside tree attained a d.b.h. of 108 cm in 48 years. Queensland kauri in natural stands add diameter slowly until they emerge above the surrounding trees (*8*). Although several trees have been recorded with d.b.h.'s of over 3 m and heights of over 60 m, and whose ages probably exceed 300 years (*9, 18*), much shorter rotations are required to be economical.

A very attractive feature of Queensland kauri is its ability to self-prune; from one-half to two-thirds of the bole will be completely free of branches (*13*), even on open-grown trees. Boles are straight with relatively small taper

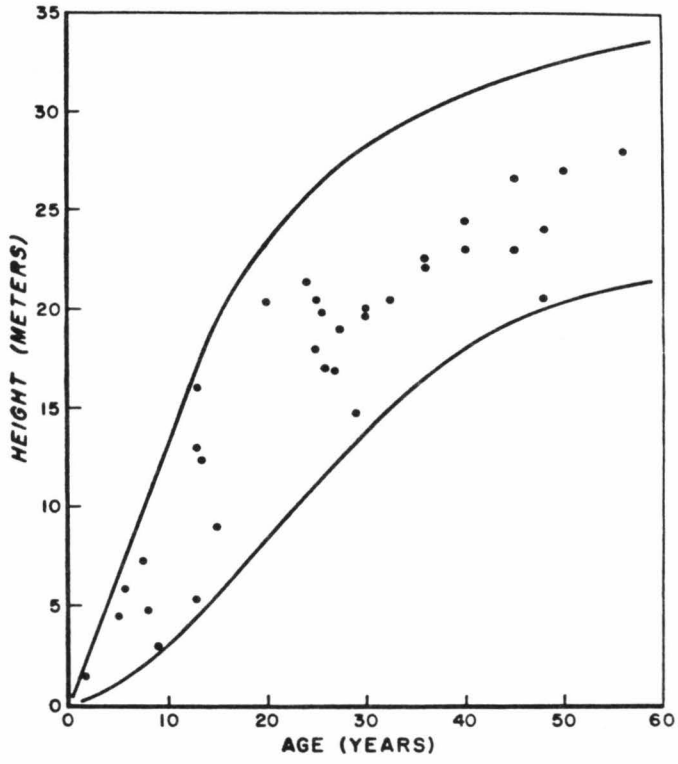

Figure 3.—*Average height-age growth curves for healthy plantations of* Agathis robusta *will probably fall between the arbitrarily drawn upper and lower curves. Data points are from the author's data and literature cited in the text.*

and no buttress (*26*). On a rotation of 50 to 60 years, Queensland kauri is capable of producing 100 percent more clear wood than pruned hoop pine (*Araucaria cunninghamii*) without the expense of pruning that is needed in hoop pine (*10*).

Wood production in Queensland kauri plantations varies from country to country. A 22-year-old stand in Queensland with a stocking of 919 stems/ha and a basal area of 35.2 m^2/ha had a mean annual volume increment of 13.8 m^3/ha. A plantation in South Africa amassed a standing volume of 1400 m^3/ha over 40 years (35 m^3/ha/yr), nearly twice that produced by *Pinus elliottii* growing nearby on a similar site (*3*). Equations for predicting tree volume based on diameter and height have been developed and are given in table 1 (*4*). Other equations predict bark thickness and commercial height at 75 mm of top diameter (*3*). Average first and second log tapers have also been characterized (*3*).

Rooting Habit.—Seedlings develop long taproots early, especially on sandy soil (*18*). Sometimes the taproot persists in older trees and several large "sinker" roots develop (*26*). Fine roots support vesicular-arbuscular mycorrhizas formed with the phycomycete *Endogone* (*26*). Rooted cuttings lack a tap root and may be prone to withdraw (*29*).

Reaction to Competition.—Queensland kauri is shade tolerant, at least when young. Trees planted under a dense canopy on Fraser Island, Queensland, were about 0.6 m tall after 40 years, yet were still able to send up vigorous shoots after the forest was cleared and burned (*21*).

Table 1.—*Prediction equations* for several traits of Queensland kauri trees*

Dependent variables	Dependent variables and coefficients	r
North Queensland Population		
Log (Volume, i.b.)§	–5.9391 + 1.671 *log* (D) + 1.218 *log* (H)	0.995
Bark thickness	2.1977 + 0.2423 (D) + 0.0553 (H)	.....
Height at 75 mm dia.	–2.5266 + 0.9779 (H)	0.981
South Queensland Population		
Log (Volume, i.b.)	–6.2026 + 2.1200 *log* (D) + 0.5652 *log* (H)	0.968
Bark thickness	0.4327 + 0.2692 (D) + 0.1688 (H)	.....
Height at 75 mm dia.	1.6464 + 0.7939 (H)	0.927

*See references 3 and 4.

§Log = common logarithm to the base 10; i.b. = inside bark; D = diameter at breast height in mm; H = total height in meters.

Seedlings of the subspecies *Agathis robusta nesophila* were able to maintain about a 70-percent relative growth rate at only 12 percent of the photosynthetically active solar radiation received by controls (*28*). Queensland kauri attains a dominant position in the forest canopy by two strategies. As a seedling or sapling, it maintains itself in the shady understory until a gap or clearing is created in the canopy. Once released, it grows rapidly (*9*). Also, Queensland kauri sometimes invades moribund secondary forests (*27*) and grows into the gaps created as old trees die. The species is not a pioneer, and new seedlings are eliminated by competition from the dense secondary forest that develops after clearcutting. Queensland kauri is not able to survive when planted on grasslands (*6*). An allelopathic effect may be involved (*26*), but exposure and intense competition are more likely reasons.

Because of its shade tolerance, Queensland kauri is recommended for underplanting (enrichment planting) (*7*), particularly when using a line planting procedure (*26, 28*). Another very good method is to plant the species with or under fast-growing but open-crowned species such as *Pinus* or *Cupressus* (*18, 19*). Planting in gaps created by logging with no other treatment would substantially increase yields, but would require a tenfold increase in kauri timber values to be economical (*4*). One author (*9*) recommended an initial plantation spacing of 3.7 by 3.7 m. Certainly in pure stands, because of the species' efficiency under low light, basal areas and stocking can be higher than for most plantation species. A basal area of 36 m^2/ha is mentioned for a 22-year-old managed natural stand in Queensland (*16*).

Damaging Agents.—In Australia, extensive defoliation of Queensland kauri by the kauri coccid (*Conifericoccus agathidis*), particularly in plantations, has made owners and managers hesitant to use the species in pure plantings (*5, 15*). A number of plantations have been clearcut because of infestations by this insect. However, Queensland kauri is still cautiously recommended for enrichment planting (*7*). This insect problem has not occurred in other countries. Other less important damaging agents in the native range are: the kauri thrips (*Oxiythrips agathidis*), a leaf cast disease caused by the fungus *Hendersonula agathi*, a weevil (*Euthyrrhinus meditabundus*), and unspecified borers (*15*). The roots of seedlings may be eaten by cane grubs or severed at the groundline by cutworms (*18*). In Puerto Rico, one case of heart-rot associated with a large basal scar is known, and several dominant trees on shallow serpentine soil have died from unknown causes. Dead timber and cut logs are attacked by shot-hole borers (*Anobium* sp.) (*9*) and powder post beetles (*Lictus brunneus*) (*14*). However, this is not a major problem in merchantable timber. Seedlings are damaged or destroyed by wallabies, opossums, and bandicoots (*9*). The species is sensitive to frost and may suffer damage in the southern parts of the native range (*9, 18*). Plantation-grown Queensland kauri have been defoliated in cyclones (*26*). On Mauritius, old trees proved windfirm in cyclones, but young ones were very vulnerable.

SPECIAL USES

Queensland kauri is one of the most valuable softwoods in the world (*5*). Its wood is pale cream to very light brown or pinkish (*13*) and without definite growth rings. Specific gravity ranges from 0.31 to 0.48 g/cc (*1, 23*). Although not of great strength, the wood is tough (*13*). It is soft, easy to bend and work, machines well, and is painted and polished easily. The wood seasons satisfactorily but shrinks both sideways and endways (*23*). Boards are not prone to warp, twist, or cup. Durability of the wood exposed to weather or in the ground is poor. Queensland kauri wood is highly regarded for cabinetry, joinery, paneling, framing, shelving, turnery, and boat building (*23*). It also makes excellent plywood (*11*) and, owing to its long fibers, is a good raw material for papermaking. Besides its timber uses, Queensland kauri is a beautiful ornamental when planted in parks, estates, and along roadside.

GENETICS

Queensland kauri is separated into three distinct populations: North Queensland, South Queensland, and Southeastern Papua New Guinea (which includes New Britain). The North Queensland population was formerly known as *A. palmerstonii*. The Papua New Guinea population was recently given subspecies status: *A. robusta nesophila* (*27*). The chromosome number of *A. dammara* is 2n = 26 (*26*); it is assumed that Queensland kauri has the same. Severe

genetic erosion is feared in some provenances of Queensland kauri because of long-term selective logging on the best mature trees (*25*).

LITERATURE CITED

1. Boland, D.J., Brooker, M.I.H.; Chippendale, G.M.; Hall, N.; Hyland, B.P.M.; Johnston, R.D.; Kleingig, D.A.; Turner, J.D. 1984. Forest trees of Australia. Melbourne, Australia: Nelson CSIRO. 687 p.
2. Bowen, M.R.; Whitmore, T.C. 1980. *Agathis*—A genus of fast growing rain forest conifers. Commonwealth Forestry Review. 59(3): 307–310.
3. Bredenkamp, B.V. 1981. Kauri pine—a place in South African forestry? South African Forestry Journal. 16: 17—22.
4. Bredenkamp, B.V.; Loveday, N.C. 1984. Volume equations for diameter measurements in millimeters. South African Forestry Journal. 130: 40.
5. Brown, A.; Hall, N. 1968. Growing trees on Australian farms. Canberra, Australia: A.J. Arthur, Commonwealth Government Printer. 397 p.
6. Commonwealth Forestry Institute. 1966. Fast growing tropical species. Oxford, England: Reference TT/5/1. Commonwealth Forestry Institute. 101 p.
7. Dale, J.A. 1983. Management studies in the escarpment rainforest of South East Queensland. Res. Pap. No. 14. Brisbane, Australia: Queensland Department of Forestry. 90 p.
8. Dallimore, W.; Jackson, A.B. 1954. A handbook of coniferae including Ginkgoaceae. London, England: Edward Arnold (Publishers), Ltd. 686 p.
9. Dunstan, T. 1928. A silvicultural note on northern kauri pine (*Agathis palmerstoni*). Bulletin No. 10. Brisbane, Australia: Queensland Forest Service. 19 p.
10. Grenning, V. 1957. Production of quality wood in coniferous plantations in Queensland. Section 4.1. 7th British Commonwealth Forestry Conference; 1957 August 26–October 10; Brisbane, Australia. Canberra, Australia: British Commonwealth Bureau of Forestry.
11. Guha, S.R.D., Singh, M.M.; Bhola, P.P.; Chittivanich, B.S.; Gay, L.S. 1970. Pulping studies of *Agathis robusta*. Indian Forester. 96(12): 866–873.
12. Haley, C. 1957. The present status of tree breeding work in Queensland. Section 6.3. 7th British Commonwealth Forestry Conference; 1957 August 26–October 10; Brisbane, Australia. Canberra, Australia: British Commonwealth Bureau of Forestry.
13. Hall, N.; Johnston, R.D.; Chippendale, G.M. 1970. Forest trees of Australia. Canberra, Australia: Australian Government Publishing Service. 334 p.
14. Heather, N.W. 1970. Susceptibility of two species of *Agathis* to attack by *Lyctus brunneus* (Steph.). Res. Note No. 21. Brisbane, Australia: Queensland Department of Forestry. 6 p.
15. Heather, N.W.; Schaumberg, J.B. 1966. Plantation problems of kauri pine in South East Queensland. Australian Forestry. 30(1): 12–19.
16. Nair, P.N. 1971. Preliminary trials with tropical conifers in Kerala State. India Forester. 97(5): 233–242.
17. Nikles, D.G. 1961. The development of a new method for grafting hoop and kauri pines. Res. Note No. 10. Brisbane, Australia: Queensland Forest Service. 31 p.
18. Petrie, W.R. 1922. A note on "Dundathu" kauri (*Agathis robusta*). Bulletin No. 4. Brisbane, Australia: Queensland Forest Service. 20 p.
19. Richards, B.N. 1961. Underplanting of exotic pines with native conifers. Forest Res. Note 16(1). Brisbane, Australia: Queensland Forest Service. 18 p.
20. Richards, B.N.; Bevege, D.I. 1968. Nutrient requirements of kauri pine on a lateritic podzolic soil in southern Queensland. Australian Forestry. 32(1): 55–62.
21. Robertson, C.C. 1926. A reconnaissance of the forest trees of Australia. Cape Town, South Africa: Cape Times Limited, Government Printers. 265 p.
22. Streets, R.J. 1962. Exotic Forest trees of the British Commonwealth. Oxford, England: Clarendon Press. 750 p.
23. Swain, E.H.F. 1928. The timber and forest products of Queensland. Brisbane, Australia: Queensland Forest Service. 500 p.
24. Whitmore, T.C. 1986. Tropical rain forest of the Far East. Oxford, England: Clarendon Press. 352 p.
25. Whitmore, T.C. 1977. *Agathis*, a fast growing conifer of the Far East rain forests. Brisbane, Australia: Proceedings: Joint IUFRO Workshop 52.02-08 and 52.03-01.
26. Whitmore, T.C. 1977. A first look at *Agathis*. Tropical Forestry Papers No. 11. Oxford, England: Commonwealth Forestry Institute. 54 p.
27. Whitmore, T.C. 1980. A monograph of *Agathis*. Plant Systematics and Evolution. 135: 41–69.
28. Whitmore, T.C.; Bowen, M.R. 1983. Growth analysis of some *Agathis* species. The Malaysian Forester. 46(2): 186–196.
29. Whitmore, T.C.; Garton, A.; Steel, J. 1985. Progress on the vegetative propagation of *Agathis*. Commonwealth Forestry Review. 64: 163–164.